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Technical Report

R 407

WASTE-HEAT SEAWATER CONVERSION
UNIT AT MARCUS ISLAND

September 1965

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U. S. NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

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INTRODUCTION

A thorough evaluation of seawater conversion equipment requires that tests be conducted under actual operating conditions. An in-service test lasting approximately one year provides data relative to the equipment's expected life, maintenance problems, and operator reaction. In order that objective reporting is obtained, the user should have a real need for the item tested.

The U. S. Coast Guard was faced with the problem of providing an emergency water supply at their Loran station on Marcus Island. Catchment areas were intended to be the prime source of water, but dry periods in excess of 3 months would entirely deplete the storage. A developmental prototype of a multistage flash evaporator for seawater conversion* was installed and successfully tested by the U. S. Coast Guard in cooperation with NCEL. The installation and test results are described on the following pages.

INSTALLATION AT MARCUS ISLAND

In response to the request by the Coast Guard, NCEL shipped the multistage flash evaporator to their Fourteenth District Headquarters in Honolulu, Hawaii. Before shipment, the unit had undergone extensive testing at the Laboratory. The evaporator consisted of 24 stages housed in four separate shells (Figure 1). The capacity was 200 gph of fresh water with a heat input of approximately 400,000 Btu/hr, the feed-water temperature was 70°F, and brine to the first flash stage was heated to 195°F. Since the operating temperatures at Marcus Island were expected to be 85°F and 185°F, respectively, reduced performance was anticipated at comparable heat input.

Because the evaporator was designed to utilize waste heat from a 60-kw diesel generator, it appeared to be a good solution for the emergency water supply at Marcus Island. The power-generating capacity was well above 60 kw, so no heat supply problem was foreseen. The engineering required for installing the unit and the installation itself were done by the Coast Guard. Three different methods of

* U. S. Naval Civil Engineering Laboratory. Technical Report R-245: Distilling sea water with diesel generator waste heat, by J. S. Williams and W. R. Nehlsen, Port Hueneme, California, 1962.

obtaining heat were suggested to the Coast Guard. Schematic drawings of each are contained in Figures 2, 3, and 4. The Laboratory was informed that a method similar to that shown in Figure 3 would be used.

Because of the difficulty of installing an open-sea intake line for water for the sanitary system, a well was drilled. This water is used for the evaporator feed as well. Percolation of rainwater into the coral dilutes the encroaching seawater. A typical analysis of the well water is given in the following table. Total solids are about one-third those of seawater. It is expected that the solids might be higher after a period of little rain.

Total hardness as CaCO_3 , ppm	2,455
"P" alkalinity (CaCO_3), ppm	0
Total alkalinity "M" (CaCO_3), ppm	264
Calcium (Ca), ppm	290
Magnesium (Mg), ppm	422
Sulfates (SO_4), ppm	960
Chloride (Cl), ppm	6,700
Silica (SiO_2), ppm	20.4
Iron and aluminum oxides (R_2O_3), ppm	46.4
Sodium and Potassium (in terms of Na), ppm	1,940
Total dissolved solids, ppm	13,410
pH, gm atm/l	7.92
Bacteriological (Coliform test)	
E. Coli (intestinal-fecal contamination)	0
Aerobacter Aerogenes (non-fecal soil), colonies/ml	670

The Coast Guard made one basic change in the unit. Instead of using the original feed-water heater, which incorporated both vapor-phase engine-jacket cooling and an exhaust-gas heat exchanger, they substituted a shell-and-tube exchanger which used only engine-jacket water to heat the seawater. This arrangement should have been entirely satisfactory, but some economies in installation rendered the system much less effective. A more detailed account will be given later in the report.

The unit was installed in the generator building in the late summer of 1963. It was first operated in September. The contractor had wired the 220-v motors to a 440-v line. All the motors were damaged and had to be rewound at the Naval Base, Yokosuka, Japan. When the motors had been replaced, an NCEL engineer went to Marcus to assist the Coast Guard personnel in starting up the unit.

UNIT OPERATION

A number of difficulties were encountered, each of which was overcome to some degree. Probably the most serious defect in the Marcus installation is the inability of the system to accept a sufficiently high feed flow. The brine heater is capable of transferring the required amount of heat from the engine-cooling water to the seawater, but with the piping system installed it is impossible to circulate sufficient engine water through the heat exchanger to take advantage of the capability. The temperature of the feed water at Marcus remains very close to 85°F all year. The design temperature for the unit was 70°F. The Coast Guard has specified a maximum engine-jacket temperature of 185°F. This limits the feed heater to a temperature of about 180°F for the outgoing seawater. Tests were made at Port Hueneme with hot seawater at 195°F. Therefore, the total temperature differential across the entire unit at Marcus Island has been decreased about 30°F.

The evaporator was originally constructed with 24 stages having fixed orifices in the brine passages between stages. Under this condition, the pressure differential between stages had to be sufficient to cause the water to flow through the unit. Flooding will occur in any stage in which the pressure does not exceed that in the succeeding stage. Flooding results in contamination of the distillate, which must be discarded. Under the design conditions, the expected pressure differential was about 18 inches of mercury. Under the conditions existing at Marcus Island, the differential is only 7 or 8 inches Hg under good conditions. During much of the test it was below 2 inches Hg. As a result, serious flooding occurred in stages 13, 14, and 15 when the flow rate exceeded 16 to 20 gpm. It is probable that flooding of previous stages would have been noticed if the first twelve had not been located above the last twelve, the drop in head thereby relieving backpressure on stage 12.

Instructions were sent to Marcus to reduce the number of stages by removing the walls between them (Figure 5). In this way, stages 14, 15, 17, 18, 20 and 21 were eliminated, reducing the number of stages to 18. The reduction did permit a higher flow through the unit, but did not produce the desired increase in performance. Examination of the data revealed another problem. The final-stage pressure was about 4 inches Hg abs instead of 2 inches, and the first-stage pressure was about 6.5 inches Hg abs instead of 10 inches. Distillate production was only 60 gph, which is less than half that expected.

ANALYSIS OF OPERATION

An NCEL engineer made another trip to Marcus to ascertain the reasons for the poor performance and, if possible, correct the deficiencies.

The vacuum system on the unit consists of a two-stage pump followed by an air eductor using motive air at atmospheric pressure. A closed-system check showed that a 26-inch-Hg vacuum was the highest possible. When the air eductor was removed, the vacuum increased to above 29 inches Hg. The two-stage pump had apparently lost enough volumetric efficiency to prevent handling the quantity of air necessary to operate the eductor.

Since 28 inches Hg is sufficient when feed water is about 85°F, the eductor was blanked off. One or two air leaks were discovered and repaired. The orifices controlling interstage venting of noncondensables were also checked and in several cases enlarged. The unit was then run to determine the effect of the changes. An improvement was noticed immediately, but the condition deteriorated within the first hour. Very little distilled water was being produced. As soon as the unit was shut down, a large quantity of distilled water was pumped out.

An air leak at the packing gland of the distillate pump was suspected, so the pump was repacked, and a rerun was made with no increase in production. The pump was dismantled and it was discovered that the nut holding the impeller on the shaft had corroded until only a shred remained. The key was not present, either having been left out or corroded entirely. With a positive suction head, the impeller clearance and speed was apparently good enough to pump water. When the 28-inch-Hg vacuum was on the last stage it would not pump. A brass key and nut were made, and the pump was reassembled. There was no further trouble.

To avoid cavitation, a slight positive discharge pressure was maintained. When the unit was returned to service, the production had increased to over 120 gph. (For short periods the engine-jacket water temperature was increased, and more cooling water was circulated through the feed heater. Production rates in excess of 150 gph were obtained.) The 120-gph rate was considered to be satisfactory for continued operation, since the daily requirement of the station varies from 2,500 to 3,000 gallons (see Table I). Each month during the test, a report of operation was received from Marcus Island. The data from these reports are tabulated in Table II.

SPECIAL TESTS

In the time remaining, the NCEL engineer conducted several experiments to obtain data which would be useful in preparing specifications for another unit. It is the intent of the Coast Guard to replace the developmental model with one which is tailored to the existing conditions.

One trial was made using water-jet ejectors for the vacuum system. Although it could be termed a "jury rig," the two jet ejectors proved satisfactory. This arrangement reduced the horsepower requirement for vacuum from 5 to 2. Motive water was recycled in a small tank (a 55-gallon drum was used) with a makeup stream of about 5 gpm to prevent temperature buildup in the tank.

Another trial run was made with a reduction in stages from 18 to 10. This resulted in a drop in production of approximately 20%. However, the modification could not adjust heat-transfer surfaces and certain other parameters, so the comparison is not entirely valid. It is certain that an eight-stage unit would produce more water than the station needs even if the present demand were doubled. To do this would require a change in the heat recovery system.

HEAT-RECOVERY SYSTEM

Although it might be construed as being outside the scope of the task, the consideration of the heat-recovery system is so important that it will be assumed to be part of the in-service test. As pointed out earlier, the system as presently installed is not efficient. A description of the generator installation will help clarify the picture. There are four 400-kw diesel generators in line, each with its own radiator located in the building wall. Under normal load, only two generators are operated.* Provision has been made to divert water from the line between the engine and radiator to the seawater heater. However, the provision is not adequate even with a modification made on one set. Figure 6 shows the arrangement as originally installed; Figure 7 shows the modification; and Figure 8 shows a recommended treatment which would provide more heat to the flash evaporator. This will be a definite economy, because the additional heat will allow a smaller investment in evaporator construction. Since the performance of a flash evaporator is so closely tied in with the quantity and temperature level of the heat source, these should be discussed as part of the in-service test.

An examination of Figure 6 will show that the circulating pump on the right is the only force moving engine water to the heat exchanger. The pump is too far from the engines, and the line is too small, to permit high-volume flow at low pressures.

Figure 7 shows a modification made by the NCEL engineer in October 1963 on No. 1 engine only. Later this piping modification was moved to engine No. 3. This increased the distance from the heat exchanger with a corresponding increase in resistance to flow. The diverting valve is controlled by a temperature sensor in

* Because the total load is less than the capacity of one generator, it would seem to be better to run only one. The standby engine would be kept warm by circulating water from the engine on the line. Operating hours of the diesels could be halved using this procedure.

the engine-water jacket. When the temperature drops, the valve directs the flow through the by-pass line. On No. 3 engine this line is blanked off, thus putting a back pressure on the line from the engine. Water is thus forced through the line to the heat exchanger. The return line comes back to the low-pressure side. The chief problem is the pressure on the hose connection at the engine. Another disadvantage is that the by-pass line cannot be used in the normal manner.

Figure 8 illustrates a change which should be an improvement. All pipe lines would be 4-inch. When this engine is not being used, valves 1 and 3 would be closed and valve 2 open. When in use, valves 1 and 3 would be open and 2 closed. The larger pipe would reduce resistance to flow and would provide maximum circulation to the heater. Fortunately, the diverting valve is a 4-inch size and would not require replacement. A circulating pump in the line may not be necessary if back pressure is not too high on the hose connection at the engine.

PUMPS

A modification which was made in February 1965 was the removal of the feed pump. Since the feed water is taken from the sanitary system, which is already pressurized, the feed pump was not required. It will now serve as a spare for the brine-discharge pump.

With the exception of the vacuum pump, all pumps are still in good condition. Some minor problems, such as that described with the distillate pump, have arisen. The answer seems to lie in strict adherence to specifications that will guarantee performance with hot seawater. The blowdown and distillate pumps should also have good NPSH characteristics. Perhaps the one single item on the unit which has caused the most trouble has been the vacuum pump. To reach and maintain the high vacuum for which the pump is intended, there can be no drop in efficiency. On three or more occasions there has been a drop — two slight and one large. The first happened during the acceptance test at NCEL and was corrected by increasing the water flow to the pump. The second happened at Marcus, necessitating a pump overhaul by the Coast Guard. Since then, the performance has dropped until it is now impossible to operate the air-jet eductor and pump together.

MATERIALS

Construction materials are also an important consideration. The unit being tested has an all-steel shell with brass tubes, tube sheets, and water boxes. Brass and steel are in contact only on the vapor side of the unit, thus minimizing galvanic action. Although corrosion of the steel shells has been quite severe due to extended periods of inactivity, there is still a comfortable margin of safety left in the wall

thickness. Extensive deterioration of the demister boxes has occurred. These are constructed of lightweight metal and, in addition, had drain holes which served as starting places for corrosion. A heavier material would rectify the problem and would not add materially to the weight or cost of the equipment.

CONCLUSIONS

In spite of the many problems experienced during the 1-1/2-year period, it is difficult to find one that would provide a basis for rejecting a multistage flash evaporator using waste heat as a method of supplying water. The test has indicated that it is probably undesirable to use so many stages, to require an extremely high vacuum, or to economize on the heat-collection system. The test has demonstrated that the system functions well with very little attention, except during start-up or at times when major load changes in the generator affect the heat input. A need for a few simple flow controls is obvious, and an effort along this line is already well underway at NCEL. The use of steel for evaporator shells appears to be undesirable for long-life expectancy or for intermittent operation where corrosion is accelerated. For periods of less than five years, steel should be satisfactory if adequate corrosion allowance is made.

The difficulty experienced with mechanical vacuum pumps shows a definite need for a more reliable system. The water-jet ejectors have demonstrated that they should be tried at the first opportunity.

Table I. Water Production and Consumption at Marcus Island

Month	Water on Hand, First of Mo. (gal)	Rainfall Increase (gal)	Evaporator Production (gal)	Water Consumed (gal)	No. of Users	Consumption per Capita (gpd)
Nov 1963	159,500	56,400	48,800	159,200	45	117
Dec	105,500	37,600	66,500	101,200	35	93
Jan 1964	108,400	55,400	34,600	77,800	50	50
Feb	120,600	8,700	18,800	72,100	50	49.7
Mar	76,000	65,200	32,200	77,500	50	50
Apr	95,900	18,590	41,700	71,120	51	46.4
May	85,070	62,230	36,000	77,500	60	42
Jun	131,000	62,000	not in operation 46,000 ^{1/}	110,000	62	59
Jul	129,000	56,000	not in operation	59,400	66	29
Aug	125,600	60,300	2 days only 4,000 ^{1/}	82,460	75	35
Sep	107,440	19,500	36,000	78,830	60	44
Oct	84,110	103,560	37,750	96,950	65	48
Nov	128,470	102,570	26,000	82,040	45	61
Dec	175,000	41,000	not in operation	62,000	40	50
Jan 1965	154,000	117,000	not in operation	105,340	37	92
Feb	165,660	18,410	27,000	61,070	35	48
Mar	150,000	34,000	33,000	64,100	38	54
Apr	152,900	37,880	14,400	99,180	43	77
May	106,000		not in operation			

^{1/} Produced by auxiliary vapor-compression conversion unit while flash evaporator was being repaired.

Table II. Operation Reports From Marcus Island

Data for Month Ending	Total Operating Time (hr)	Average Production (gph)	Feed Water Flow Rate (gpm)	Temperature (°F)						Pressure (psia)		Salinity (gr/gal)	Remarks	
				Engine Water to Heat Exchanger		Seawater to Heat Exchanger		Feed Water	Waste Brine	First Stage	Last Stage			
				In	Out	In	Out							
30 Nov 1963	414	117.8	20	191	—	155	178	84	—	10.25	5.5	0.3	Installed proper 3-way valves in engine cooling system	
31 Dec 1963	566	117.5	19	191	—	155	178	84	—	10.25	5.5	0.3		
31 Jan 1964	288	120	18	189	81	8	8	84	—	10.25	5.5	2.5		
28 Feb 1964	312	60	15	189	189	8	8	8	—	6.75	2.75	2.5		
31 Mar 1964	538	60	15	185	184	8	8	8	—	6.75	2.25	2.5		
30 Apr 1964	696	60	16	185	184	8	8	8	—	6.75	2.25	2.5	Station reports that unit requires "very little attention from operator."	
31 May 1964	600	60	16	184	184	8	8	8	—	6.75	4.0	5.5		
30 Jun 1964														Unit was not operated during June and July, and only 2 days in August. Vacuum pump required repairs.
31 Jul 1964														
31 Aug 1964														
30 Sep 1964	600	60	20	184	182	8	173	8	—	5.75	4.0	2.0	Modified evaporator by cutting out walls between some stages	
31 Oct 1964	624	60	20	184	180	8	8	8	—	7.0	6.0	2.8	Removal of six stages permitted increased flow, but did not improve performance	
30 Nov 1964	432	60	20	184	180	8	8	8	—	7.0	6.0	2.8	Not in operation because of adequate rainfall	
31 Dec 1964													Not in operation because of adequate rainfall	
31 Jan 1965													Not in operation because of adequate rainfall	
28 Feb 1965	216	128	26	180	178	152	172	83	97	9.0	2.0	2.0	Repairs made by NCEL engineer	
31 Mar 1965	264	128	26	180	178	151	171	83	97	—	1.9	—	Salinity meter out	
30 Apr 1965	240	60	10	179	177	144	170	82	—	—	—	0.5	Did not record pressures	
31 May 1965													Not in operation	

J/ Broken thermometer.

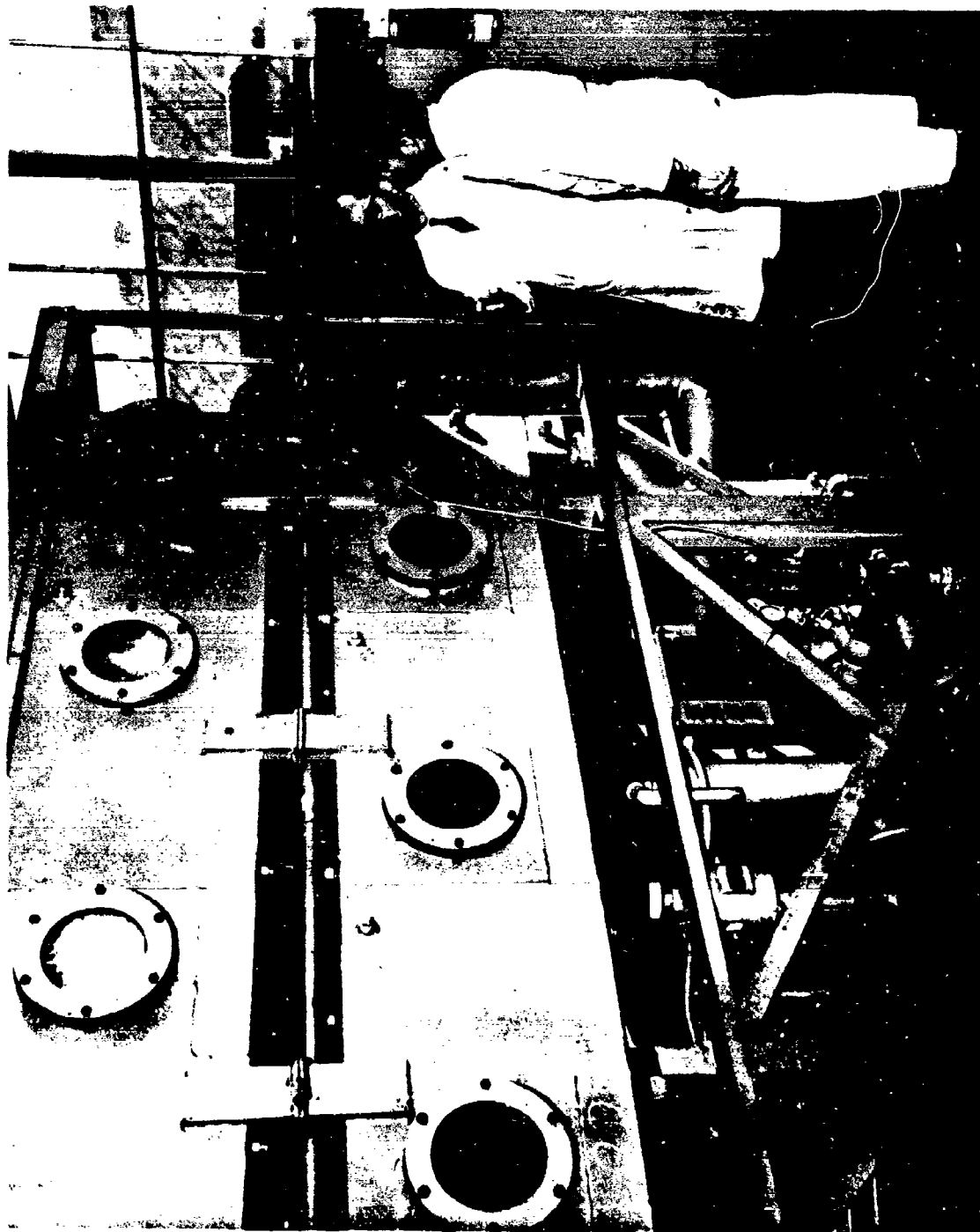


Figure 1. Evaporator under test at NCEL. Stages 1, 2, and 3 at top (right to left) and 22, 23, and 24 at bottom (left to right).

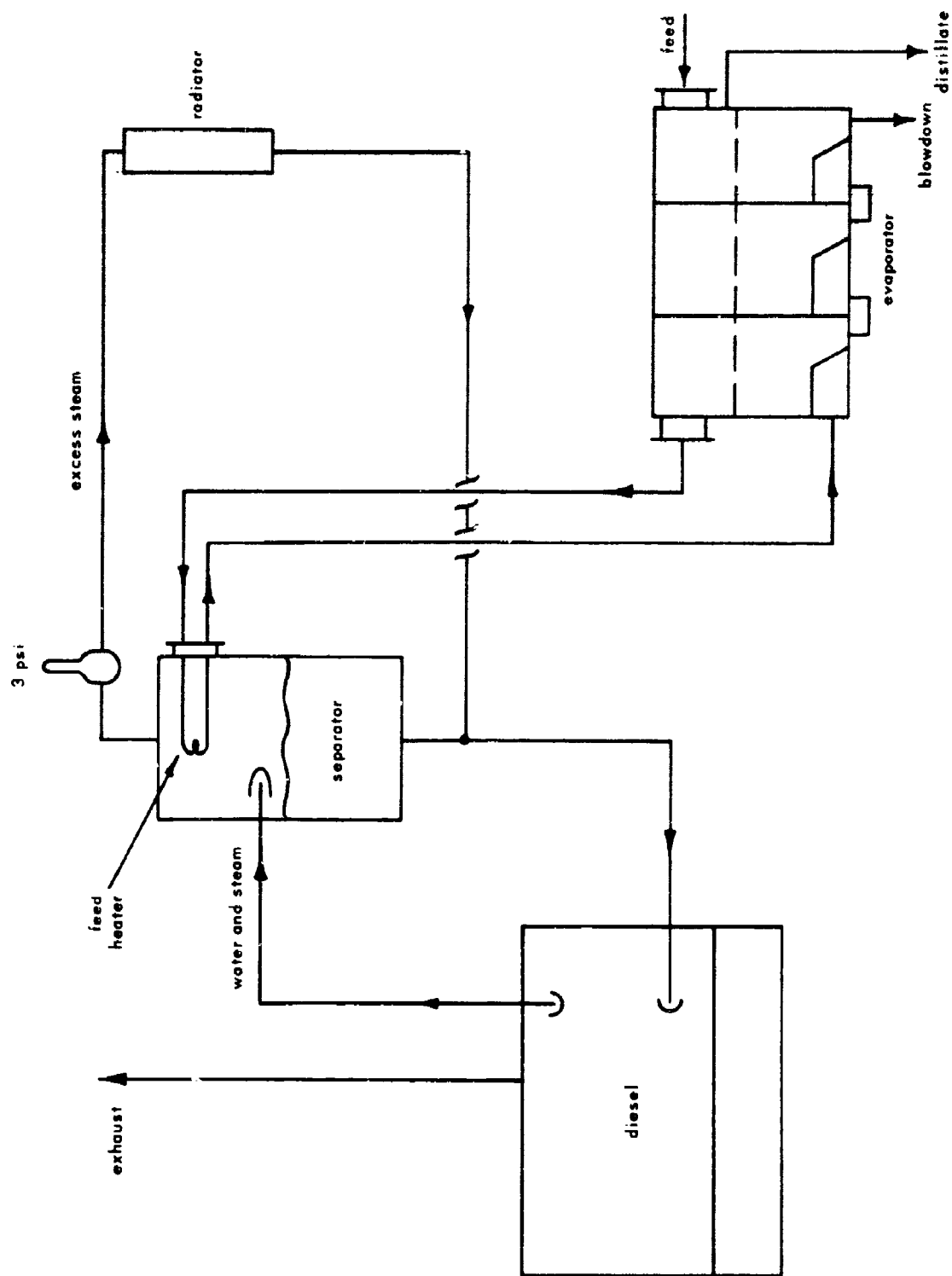


Figure 2. Heat recovery using vapor-phase system.

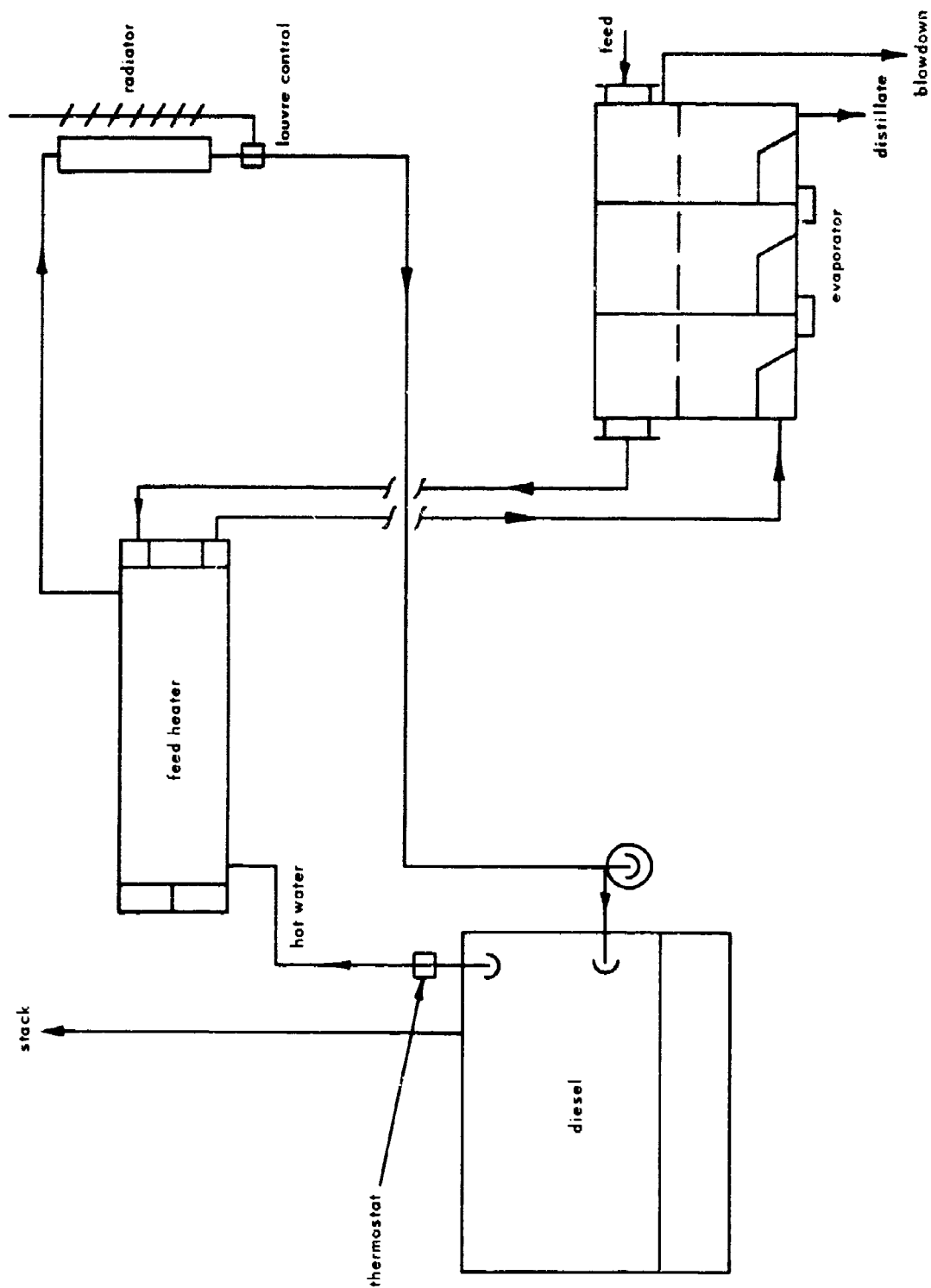


Figure 3. Heat recovery using engine-jacket water.

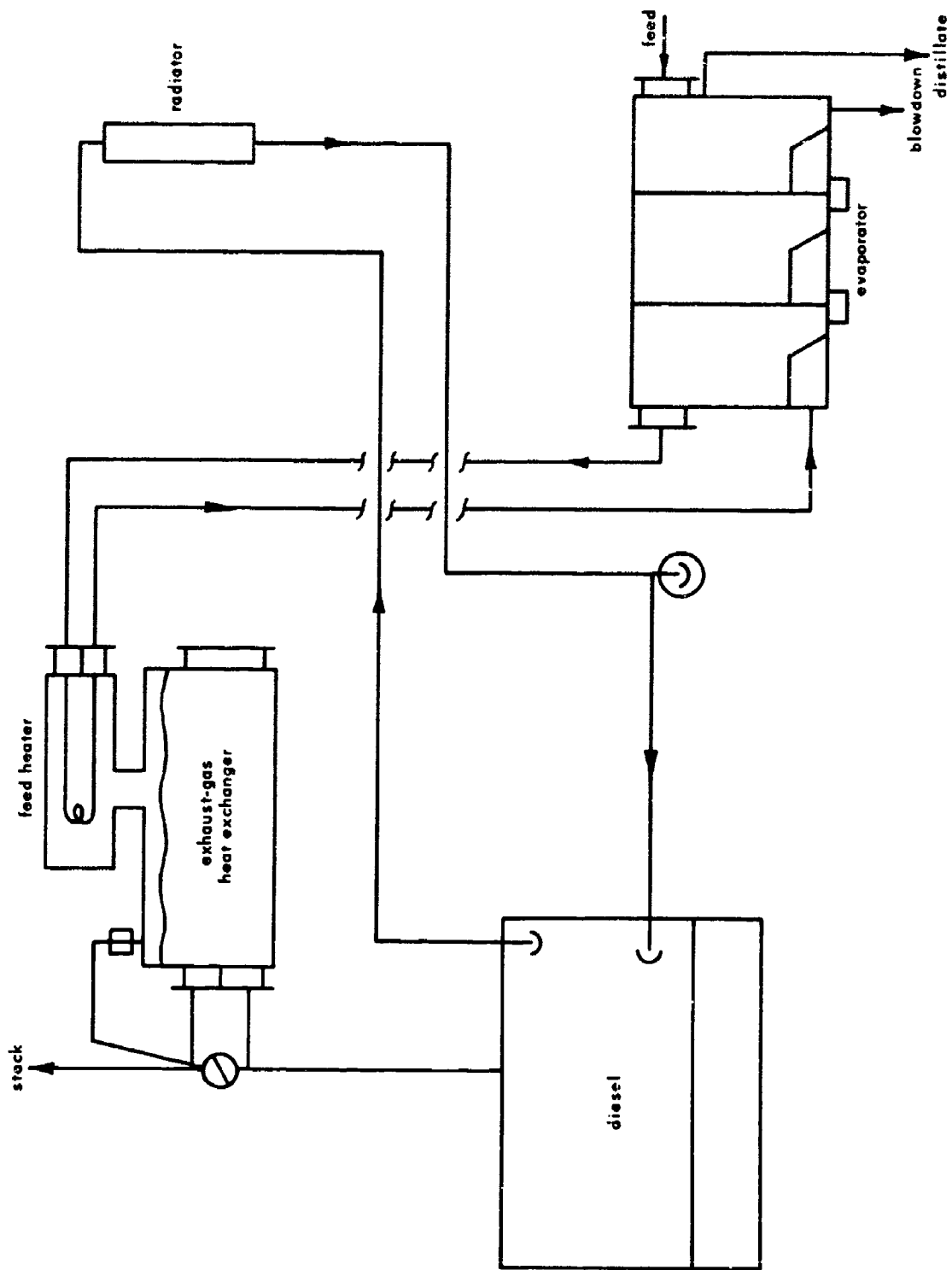


Figure 4. Heat recovery using engine exhaust.

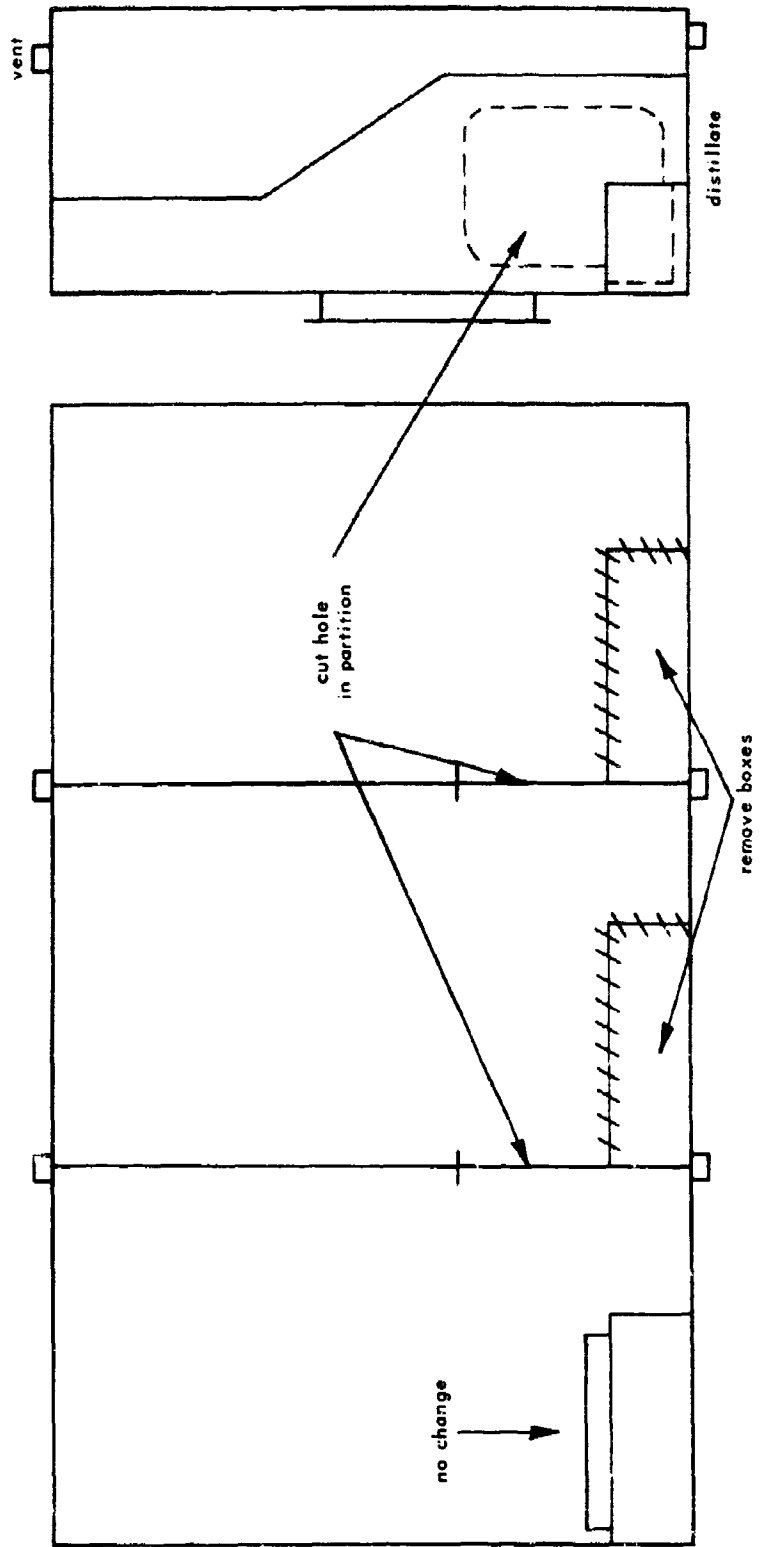
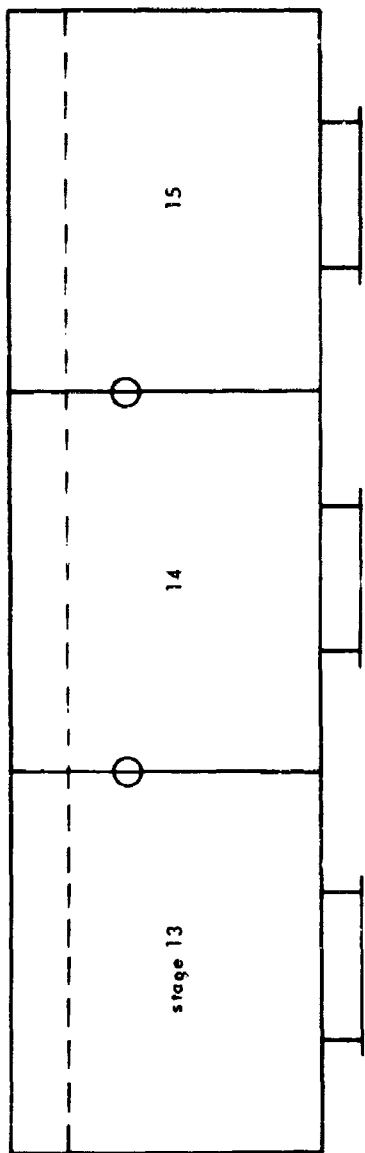


Figure 5. Suggested modification to flash evaporator.

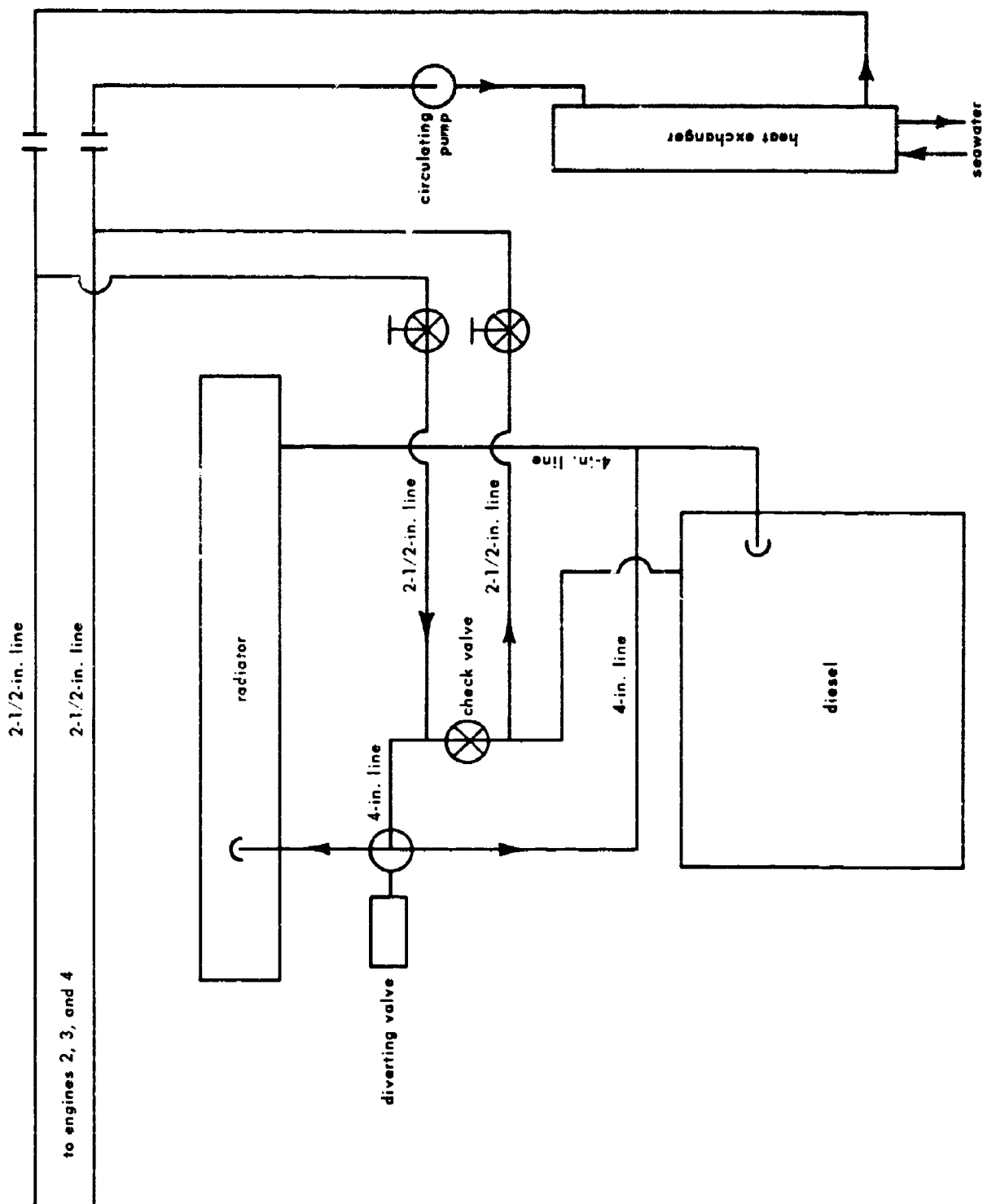


Figure 6. Original piping.

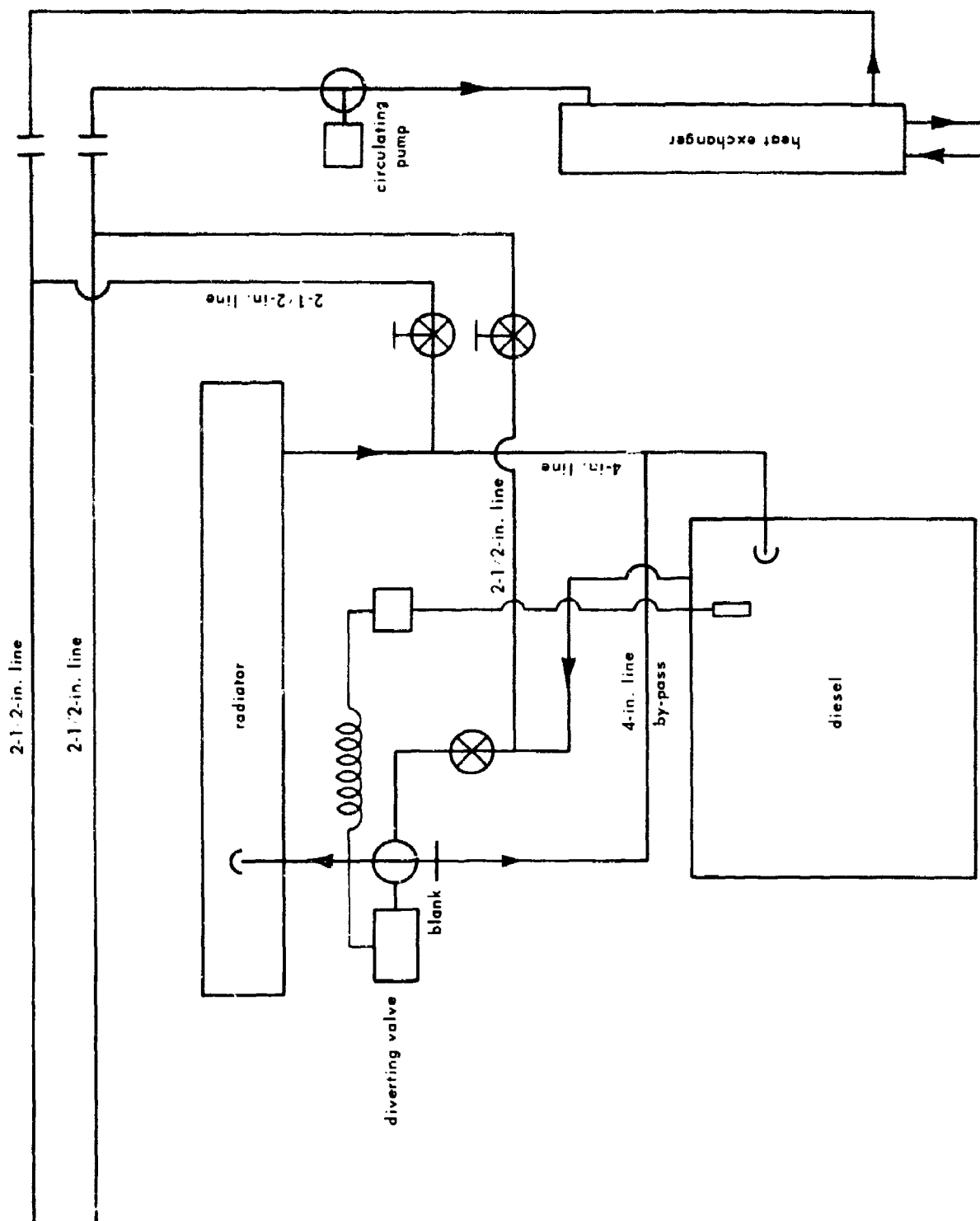


Figure 7. Modified piping.

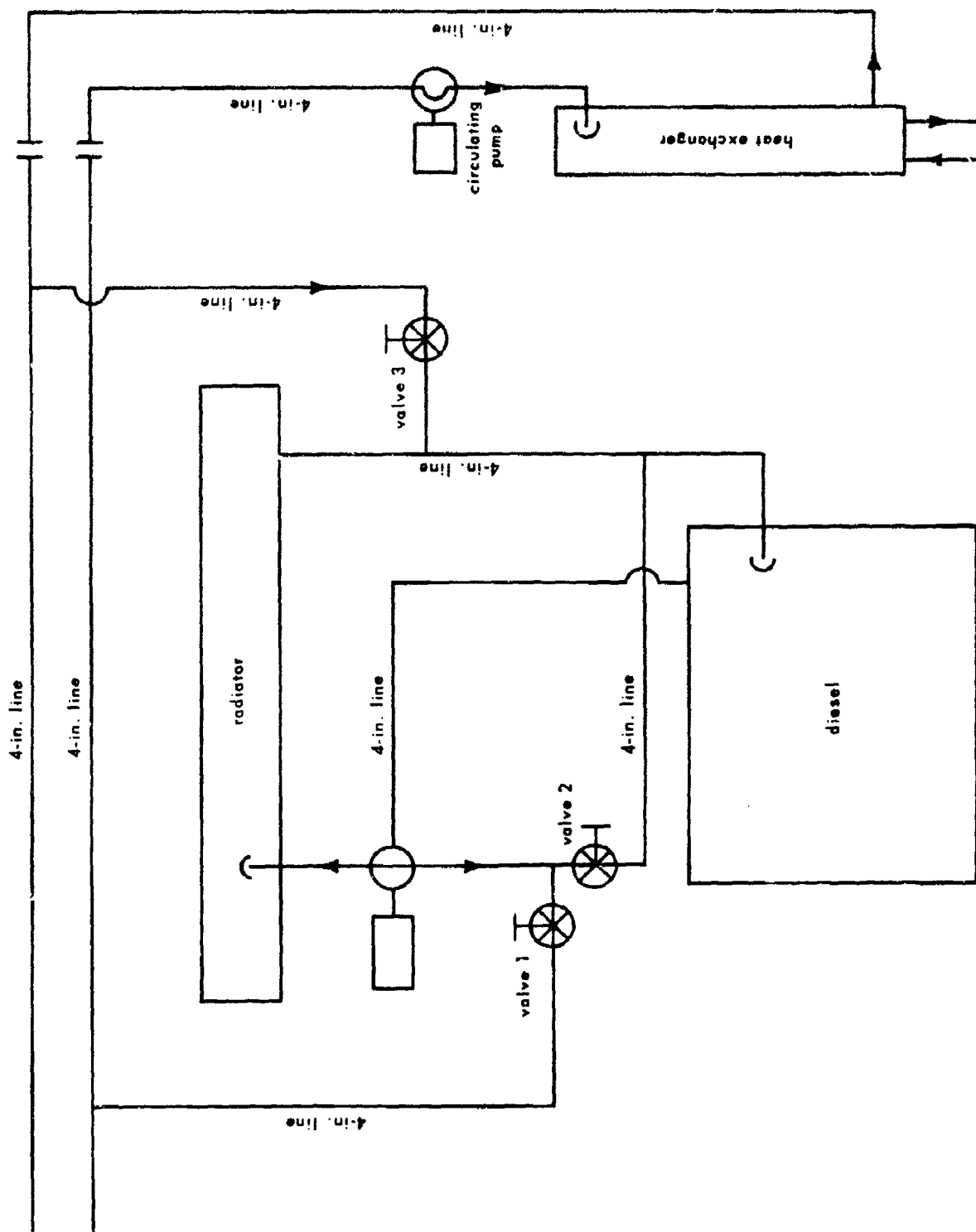


Figure 8. Proposed piping.

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U. S. Naval Civil Engineering Laboratory
WASTE-HEAT SEAWATER CONVERSION UNIT AT MARCUS ISLAND,
by J. S. Williams

TR-407 21 p. illus Sept 1965 Unclassified
1. Seawater conversion — Waste heat 2. Flash evaporator
1. Y-F015-99-01-069

An in-service test of a developmental multistage flash evaporator utilizing rejected heat from a diesel generator is described. Some background information is given, as well as test results covering a 20-month period. It is concluded that the system furnishes a very satisfactory means of providing potable water from a sea water source. The importance of proper installation is also pointed out.

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U. S. Naval Civil Engineering Laboratory
WASTE-HEAT SEAWATER CONVERSION UNIT AT MARCUS ISLAND,
by J. S. Williams

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